Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2021, 8(4):71-80**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Investigation of Dumpsite Leachate using Electrical Resistivity Tomography at Umueze-Ibeku, Umuahia, South-Eastern Nigeria

Magnus U. Igboekwe, Isaac O. Agada*, Chukwunenye Amos-Uhegbu

Department of Physics, College of Physical and Applied Sciences, Michael Okpara University of Agriculture Umudike, Abia State, Nigeria
*agadaisaac45@gmail.com

Abstract The investigation of leachate production at the Umueze-Ibeku dumpsite was conducted with the objectives of identifying the presence of leachate contaminants at the refuse dumpsite using Electrical Resistivity Tomography (ERT), and determining the extent and depth of contamination using ERT. Electrical Resistivity Tomography (ERT) using Wenner electrode configuration was deployed with a profile length of 100m at the dumpsite and a control point. The Res2Dinv software was used to model data generated from the IGIS Resistivity meter used for ERT data while Maps were produced using google earth and surfer 13 software, while geologic maps were produced using ArcGIS software. The result of ERT conducted at the over 15 years dumpsite indicated the presence of leachate with resistivity values ≤ 8.71Ωm and up to 18.8 Ωm with active concentration at between 25m to 75m along the horizontal profile in 2-Dimension. The identified leachate has penetrated a depth of 11.35m. This implies that infiltration and percolation of leachate into the ground is yet to reach the aquifer, hence borehole waters are not yet affected by the dumpsite leachate but will eventually be polluted as the leachate continues to infiltrate and percolate.

Keywords Leachate, contaminants, Electrical Resistivity Tomography (ERT), Umueze-Ibeku, Dumpsite

Introduction

The practice of uncontrolled waste disposal systems in Nigeria and Umuahia in particular can render ground and surface waters unsafe for human, agricultural and recreational use [1]. Umueze-Ibeku is also not left out in the open dump waste disposal trend which has become a concern to researchers as its impact on groundwater could be a disaster to the community. In the works of [2] 'open dumpsite describes a land where solid waste is deposited with no regulation or minimal control measures to safeguard the immediate environment'. It is an uncontrolled and illegal waste disposal point which is open and does not have a leachate collector neither is it covered at the top with earth. [3] defined refuse (solid waste) as undesirable materials which emerge from anthropogenic activities. The pattern/ method of refuse disposal have the potential to determine to a large extent the wellbeing of human population in a geographical location.

Leachate is the fluid that filters through solid wastes in dumpsites. It is produced when rainwater permeates through the waste materials in a landfill/dump. Composition of the resulting leachate varies according to the nature of the landfill material, which may include biodegradable/ non-biodegradable, organic/ inorganic and toxic/non-toxic waste [4]. When these substances escape from dumpsites, it dissolves into groundwater [5] & [6], rendering it unhealthy for human consumption and other domestic purposes. However, the degree of contamination of groundwater quality due to leachate permeation depends upon on various variables like chemical composition of leachate, precipitation, depth and distance of the well from the contamination source [7].

As expressed by [5], poor management of solid waste materials has resulted to a lot of disastrous effects such as aesthetics, environmental hazards and pollution. Common material disposed at open dumpsites include organic kitchen refuse, insecticides, pesticides, batteries, faecal waste, electronics waste, painting waste, hydrocarbon containing materials, textiles, plastics, nylon, detergents, etc. These can increase trace metals and non-metals, chemicals, biochemical and pathogens among other contaminants in dumpsites whose flow into surface and groundwater can undoubtedly result to pollution.

Statement of the problem

The Umueze dumpsite developed as a result of community effort (possibly due to ignorance) to halt the fast growing Emede/Umueze chain gully with the gully head located in Umueze which claimed arable lands and threatened residential buildings. Dumping of refuse at the site has continued for over 15 years at a distance of less than 20m from residential buildings and schools hosting both private and commercial boreholes. In the words of [8], areas near dumpsites are most likely to experience subsurface water contamination as a result of leachate emanating from pollution sources.

Considering the effect of a contaminated commercial water source on the populace cum possible outbreak of diseases and epidemic within the catchment including its short and long term implications, it becomes expedient for an in-depth understanding of the likelihood of subsurface water pollution due to leachate within the vicinity and environs of the dumpsite.

Leachate Survey using Geoelectric techniques

In investigating the presence of leachate in the subsurface, geoelectric technique such as Electrical Resistivity Tomography (ERT) is used since it provides a 2-Dimensional image of rocks with appropriate resistivity values while 1-Dimensional VES was used to validate and compliment the ERT.

1. Electrical Resistivity Tomography

Electrical Resistivity Tomography (ERT) otherwise known as Electrical Resistivity Imaging (ERI) is a non-invasive method with very outstanding features and ability, relevant for understanding the sub-surface formations and for depth estimations of natural resources [9]. ERT measures resistivity variations, both in lateral and vertical directions using multi electrode system connected to multi-core cable. ERT operates on the principle of ohms law which states that the electric current I in a conducting wire is proportional to the potential difference V across it [10]. This is mathematically expressed as

Voltage (V) = Current (I) x Resistance (R)

$$V=IR \qquad (1)$$

Knowing that the resistance (R) is directly proportional to it's length (l) and inversely proportional to the cross-sectional area (A), it follows that

$$R = \rho\frac{l}{A} \qquad (2)$$

$$\rho = \frac{RA}{l} \qquad (3)$$

where ρ = Resistivity

ERT finds application in groundwater exploration, freshwater invasion by salt water, geotechnics (detection of a fault in a hard rock), delineation of a dumpsite, discovery of buried antiquities and detection of a metallic orebody [11]. This implies that the use of ERT in the study of leachate production at Umueze-Ibeku dumpsite is a step in the right direction. The Wenner ERT survey technique was adopted in this research.

Wenner Array

The wenner configuration of four electrodes is made up of equal number of source and receiver electrodes have a common mid-point with equal spacing between adjacent electrodes [10]. This configuration has moderate depth of penetration, strong signal strength and ability to manage background noise [12]. Its depth of penetration is related to1/2 the outer electrode spacing.

The Wenner configuration for ERT has A and B as current electrodes, M and N as potential electrodes, with 'a' as the electrode spacing as shown below (Fig. 1).

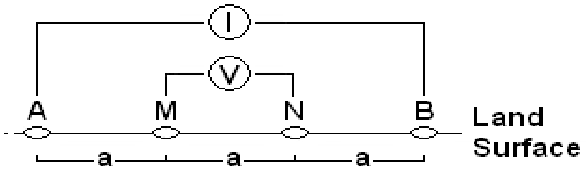


Fig. 1: The Wenner Configuration

The apparent resistivity for the wenner array is given by the formula:

$$\rho_a = 2\pi a\left[\frac{V}{I}\right] \qquad (5)$$

$$\rho_a = G\left[\frac{V}{I}\right] = GR \qquad (6)$$

where,

ρ_a = Apparent resistivity, a = Distance between two electrodes, V = Potential difference between potential electrode and I = Current sent into the ground and Geometric factor G = 2πa

Table 1: Resistivity Values of Rocks and Subsurface Materials

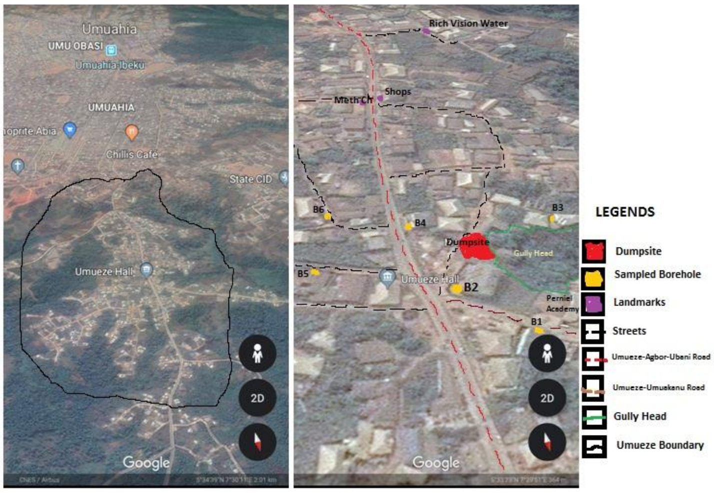
Resistivity (ohm-m)	Soil type/ Lithology
20 - 40	Clay-sand
40 – 60	Sand-clay
5 – 100	Clay
10 – 1000	Unconsolidated shale
20 - 2000	Consolidated shale
250 – 500, 2000 - 3400	Sand
4	Ash
100 - 10000	Saturated sand
150	Saturated sandy soil
500 - 10000	Limestone
200 - 8000	Sandstone
0.6 – 5	Dry sand contaminated
1 - 5	Leachate
100	Saturated gravel
250 - 1700	Top soil
30 - 215	Sand clay/ clay sand
300 - 3000	Slate
50 - 3000	Shale
25	Saturated sandstone
20	Saturated Clayey soil
10 - 800	Alluvium and sand
$50-10^7$	Limestone
Less than 10 - 50	Landfill runoff
15 - 30	Saturated landfill
30 - 100	unsaturated landfill
800 - 1500	Laterite
50 - 100	Pulverised fuel ash

Culled from [12], [13] & [14]

The Study Area

Umueze-Ibeku located between Latitude 5.54608° and 5.56128° and Longitude 7.49625° and 7.49822°. The dumpsite of interest is located at a gully head between Latitude 5.55317° and 5.55344° and Longitude 7.49642° and 7.49650°, with elevations of between 135m and 130m above mean sea level along the Umueze-Agbor-Ubani road.

Figure 2: The Dumpsite along Umueze-Agbor-Ubani road.



GOOGLE EARTH MAP SHOWING UMUEZE BOUNDARY, DUMPSITE AND SAMPLED BOREHOLES

Figure 3: Google Earth Map of Umueze-Ibeku showing the dumpsite and Sample borehole locations

Geology

Umueze-Ibeku is underlain by the Bende-Ameki formation. According to [15] & [16], the Bende-Ameki Formation consists of unconsolidated fine-medium-coarse-grained sandstone, clayey sandstone and shale. [17] remarked that the formation has sandy shale at very low shallow depth with underlying shale beyond 30m depth.

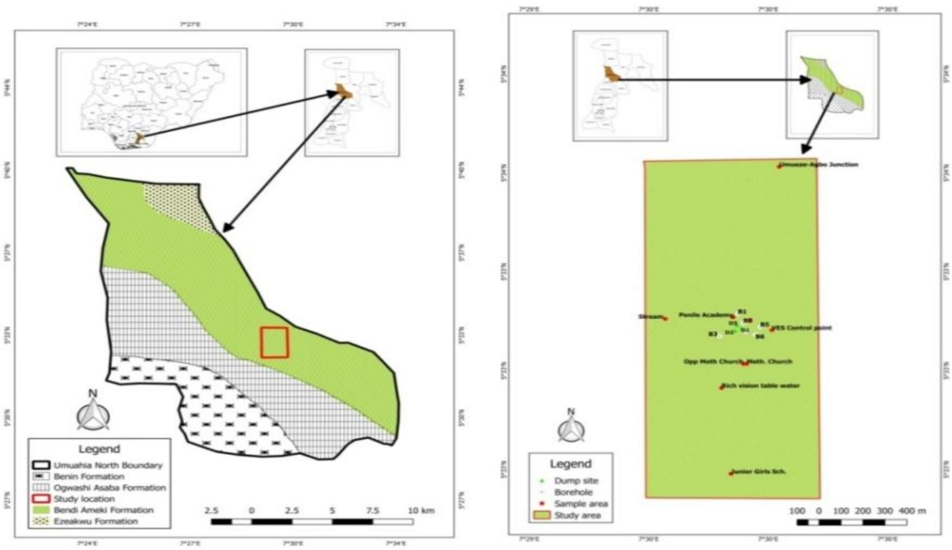


Figure 4: Geologic Map of the Study Area

Materials and Methods

Materials:

Materials used to execute the survey are the resistivity data measuring instrument, hammer, multi-core cables with crocodile clips, GPS device, electrodes and writing materials. Principal among these materials is the resistivity data measuring instrument.

The Integrated Geo- Instrument Services (IGIS) device with model: SSR-MP-ATS is a multi electrode meter used to collect resistivity data without wasting power which enhances its signal strength to probe deeper layers with relatively low power inputs. It can be used for depths of up to 600m under favourable geological field [18].

Method

The 2-D Electrical Resistivity Tomography was used in achieving the objective of the research. Two (2) ERT profiles were conducted with one at the dumpsite and the other as a control (a location away from the dumpsite but within the study area). As a result of limitation of space and the fact that the dumpsite is within a 'difficult terrain', several profiles could not be conducted. Below is the outcome of ERT in the study area.

The field set-up covered a distance of 100m with the dumpsite as mid-point. A total of 22 electrodes were plugged into the ground at a fixed spacing, every 5m. The measured data were subjected to a least-square inversion process RES2DINV (ver 5.1). Outcome of geotechnical survey will provide information on the subsurface lithology, presence of leachate at the dumpsite and depth of contamination.

Resistivity values are expressed in ohm-metres (Ωm)

Results & Discussion

Results

The result of ERT conducted at the dumpsite and a control point is as presented below.

Electrical Resistivity Tomography (ERT) result

ERT conducted in the study involves the combination of Horizontal Resistivity Profiling (HRP) and Vertical Electrical sounding (VES) using the IGIS device which gave a 2 dimensional imaging of the subsurface. Wenner electrode configuration was used with electrode spacing of 5m and a profile length of 100m.

Electrode configuration is Wenner Array; Array mid-point was at 50.000m. Datum points of the profile is as shown in Fig. 5 below

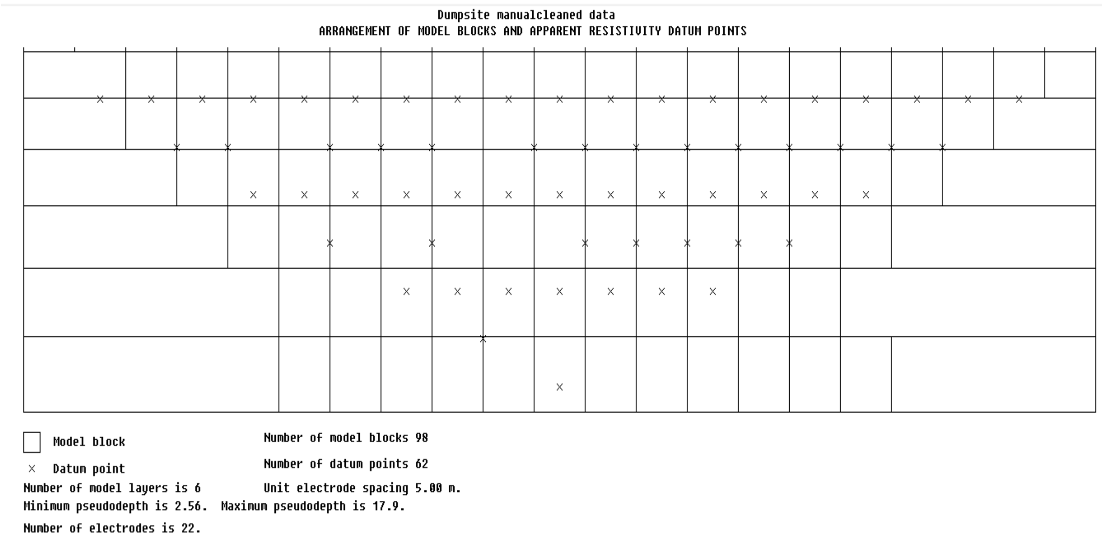


Figure 5: ERT Profile of the Study Area

Two (2) ERT profiles were conducted with one at the dumpsite and the other as a control (a location away from the dumpsite but within the study area).

Table 3: ERT Data at the Dumpsite

k	Resistance at 5m	Apparent Resistivity	Resistance at 10m	Apparent Resistivity	Resistance at 15m	Apparent Resistivity	Resistance at 20m	Apparent Resistivity	Resistance at 25m	Apparent Resistivity	Resistance at 30m	Apparent Resistivity	Resistance at 35m	Apparent Resistivity
6.284	1.77846	55.87921	2.06841	129.9789	0.4683	44.14196	0.45056	56.62638	1.17054	183.8918	0.1345	25.35594	2.76675	608.519
6.284	1.6056	50.44795	0.8734	54.88446	0.26096	24.59809	1.52666	191.8706	2.5212	396.0805	2.26256	426.5378		
6.284	1.87405	58.88265	0.35495	22.30506	0.39471	37.20536	1.05171	132.1789	2.30957	362.8334	2.12228	400.0922		
6.284	1.0525	33.06955	0.55801	35.06535	0.40867	38.52123	0.21826	27.43092	2.01735	316.9257	1.982	373.6466		
6.284	0.92456	29.04968	0.77215	48.52191	0.47171	44.46338	1.0405	130.77	1.63835	257.3848				
6.284	0.63337	19.90049	0.76623	48.14989	1.24256	117.1237	0.3874	48.68843	1.25935	197.8439				
6.284	0.48444	15.2211	0.34362	21.59308	1.69392	159.6689	0.38256	48.08014	1.53361	240.9301				
6.284	0.33551	10.54172	0.8922	56.06585	2.14528	202.2141	0.28991	36.43589						
6.284	0.65481	20.57413	1.3045	81.97478	1.89847	178.9498	0.86718	108.9872						
6.284	1.78386	56.04888	1.67893	105.504	1.65166	155.6855	1.44445	181.5385						
6.284	1.97642	62.09912	2.12815	133.7329	1.60369	151.1638								
6.284	0.99617	31.29966	2.2765	143.0568	1.55572	146.6422								
6.284	1.13507	35.6639	2.4249	152.3807	1.05965	99.88261								
6.284	0.994975	31.26211	4.50637	283.1803										
6.284	0.85488	26.86033	2.62801	165.1441										
6.284	1.10067	34.58305	2.31326	145.3653										
6.284	2.82467	88.75113												
6.284	4.85521	152.5507												
6.284	4.47157	140.4967												

The ERT data for the dumpsite presented in table 4.1 above probed a depth of 19.8m and was modeled using RES2DINV. This produced a two (2) dimensional model of the earth surface beneath the dump. Considering the inverse model resistivity section in Fig 4.1, areas having very deep blue and deep blue colouration have resistivity values ≤8.71Ωm to 18.8Ωm. This is indicative of leachate which is a liquid substance with low resistivity, containing highly conductive substances. Other geologic materials identified in the dumpsite inverse model resistivity section are clay, sand and shale

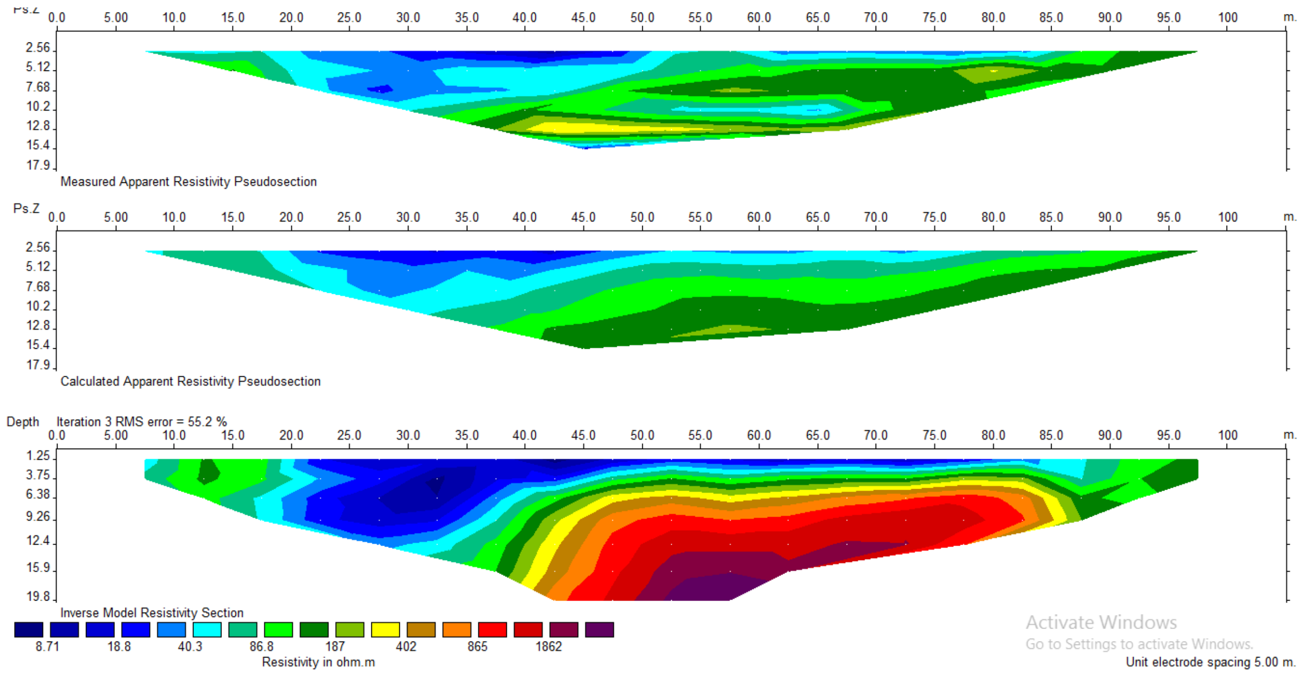


Figure 6: ERT Model at the Dumpsite

ERT profile at the control is as presented in Table 4.2, with resistivity values at 5m, 10m, 15m, 20m, 25m, 30m and 35m electrode spacing.

Table 4: ERT Data at Control Point

k	Resistance at 5m	Apparent Resistivity	Resistance at 10m	Apparent Resistivity	Resistance at 15m	Apparent Resistivity	Resistance at 20m	Apparent Resistivity	Resistance at 25m	Apparent Resistivity	Resistance at 30m	Apparent Resistivity	Resistance at 35m	Apparent Resistivity
6.284	3.8932	122.3228	2.2517	141.4937	0.6406	60.3858	1.3754	172.8578	1.3715	215.4548	0.6738	127.0191	0.6962	153.1288
6.284	4.3405	136.3769	2.6023	163.5260	1.9339	182.2875	1.3804	173.4862	0.9575	150.4295	1.0578	199.4089		
6.284	0.9686	30.4334	0.9065	56.9613	1.7879	168.5275	1.3004	163.4318	1.1842	186.0315	3.0481	574.6222		
6.284	4.7664	149.7593	1.6890	106.1355	1.3728	129.3954	1.7513	220.0971	1.4246	223.8062	1.4864	280.2105		
6.284	3.2645	102.5709	1.1241	70.6353	0.1849	17.4277	1.9175	240.9914	1.6354	256.9151				
6.284	4.4668	140.3469	3.4702	218.0699	2.1343	201.1791	0.8225	103.3718	2.5167	395.3767				
6.284	5.9099	185.6894	2.7446	172.4707	2.9799	280.8844	2.2406	281.5923	2.4858	390.5145				
6.284	4.9849	156.6256	2.7843	174.9623	4.2846	403.8673	2.0901	262.6787						
6.284	3.2965	103.5760	1.9122	120.1595	2.7561	259.7909	2.1029	264.2887						
6.284	4.5216	142.0671	3.8747	243.4868	3.2212	303.6256	3.0519	383.5666						
6.284	5.4416	170.9757	3.8609	242.6164	4.0266	379.5435								
6.284	3.5111	110.3200	4.4025	276.6531	4.8308	455.3522								
6.284	4.7263	148.5013	5.6082	352.4161	3.4743	327.4856								
6.284	7.5798	238.1564	6.0719	381.5557										
6.284	7.8333	246.1207	4.3031	270.4068										
6.284	8.2827	260.2427	1.3934	87.5619										
6.284	11.1068	348.9757												
6.284	7.3176	229.9190												
6.284	15.8195	497.0487												

ERT least square inversion model (Fig. 4.2) at the Control showed a depth of investigation of 19.8m with a 100m horizontal distance. Low resistivity mixed clayey layer was identified between 15m to 20m horizontally up to a depth of 6.38m; and 40m to 47m below 9.26m depth. Apparent resistivity value of dominant top layer is more than 80.6Ωm which is not indicative of leachate a proof that the dumpsite generates leachate. Geologic materials identified are clay, sand and shale.

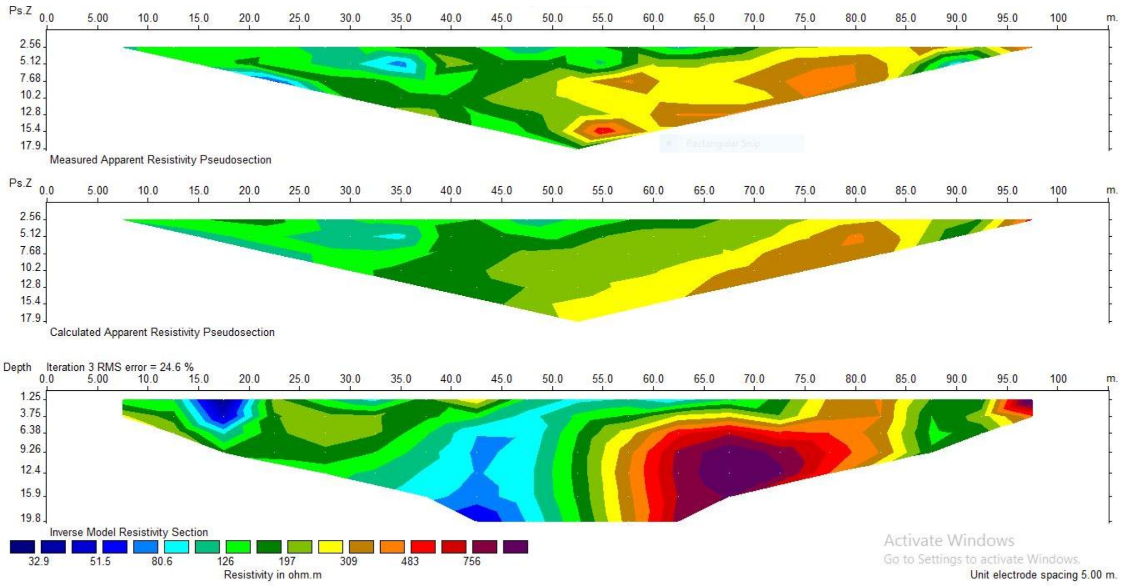


Figure 7: ERT Model at the Control Site

Elevation Contour, 3-D surface and Vector grid maps were produced as seen in Fig. 4.6, Fig. 4.7 and Fig. 4.9 using Surfer 13 software. As can be seen in the Figures, the land area slopes towards the NE direction where the stream is located. The dumpsite (D1, D2, and D3 at the gully head) arced by the sampled boreholes is on a higher elevation.

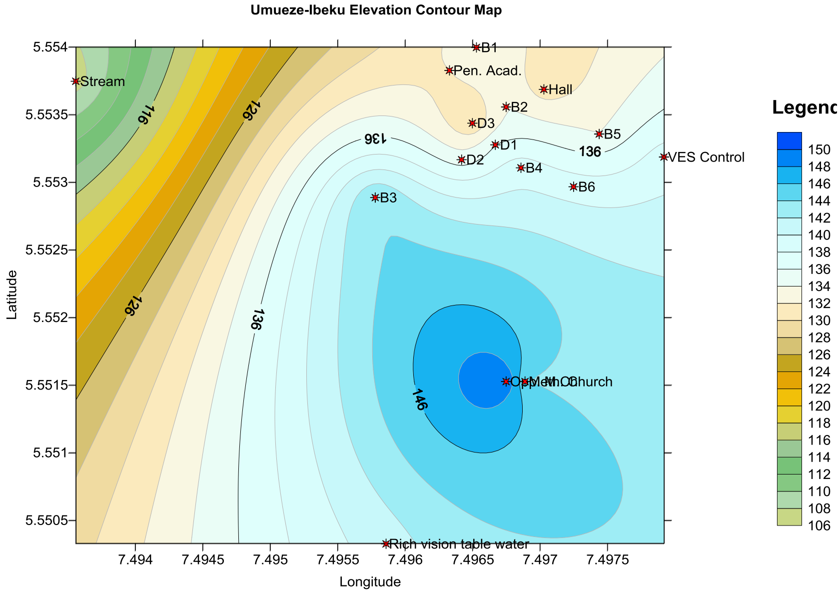


Figure 8: Elevation Contour Map of Umueze-Ibeku

Groundwater flow within the area typifies the surface flow with higher strength of flow around the gully head upstream, which reduces as water flows downstream as seen in Fig. 4.8

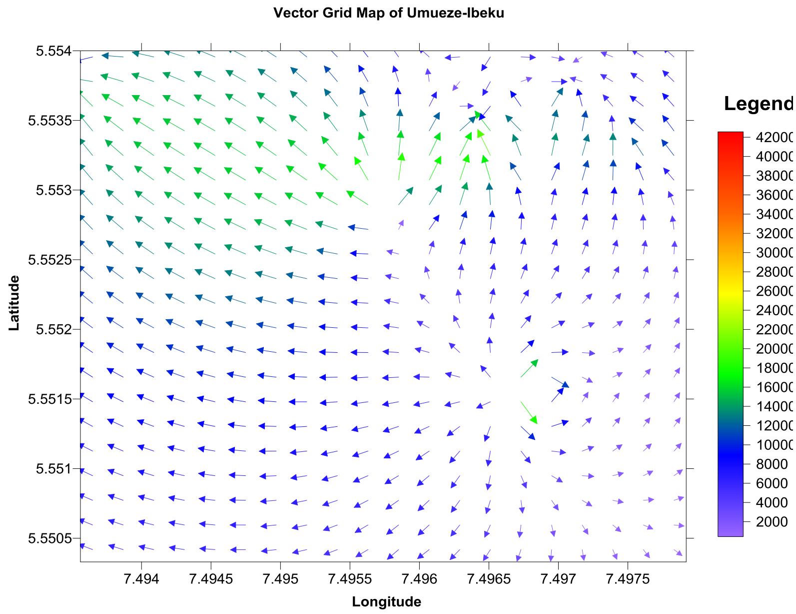


Figure 9: Grid Map of Umueze-Ibeku showing Flow Direction

Discussion

Low resistivity can be as a result of leachate, clay or clay leachate mixture. Resistivity as a result of leachate in land fill runoff can be less than 10Ωm, sometimes slightly above 10Ωm as confirmed in the works of [13] & [14].

ERT least square inversion model (Fig. 5) at the dumpsite probed a depth of 19.8m with a profile length of 100m (horizontal distance). Leachate was identified at between 25m to 75m. Area between 40m to 50m, 60m to 65m and around 70m (the very deep blue colour) is considered as zone 1 which has the lowest resistivity values

≤ 8.71Ωm. This is the area with the contaminant leachate plume. Furthermore, areas on the model with resistivity values between 8.71Ωm and 18.8Ωm (deep blue colour) form zone 2 which is the region with the migrating leachate plume in the soil. Areas with other colours form zone 3 which is regarded as yet to be impacted areas having resistivity values above 18.8Ωm and above. Leachate with apparent resistivity of between 1 - 18.8Ωm identified has penetrated a depth of about 11.35m. Flow of the leachate is in the direction of 0.00m, in the direction of slope, towards places with lesser elevation (this is further confirmed in contour and flow direction maps presented above in Fig. 10 and 12 respectively).

ERT least square inversion model (Fig. 6) at the Control showed a depth of investigation of 19.8m with a 100m horizontal distance. Low resistivity mixed clayey layer was identified between 15m to 20m horizontally up to a depth of 6.38m; and 40m to 47m below 6.38m depth. Apparent resistivity value of dominant top layer is more than 80.6Ωm which is not indicative of leachate a proof that the dumpsite generates leachate.

From the inversion model displayed for the dumpsite and control (Fig. 5 and 6 respectively), it is obvious that they have similar geology and lithology of sand, clay and shale [15], [16] & [17] but the dumpsite is on a much higher elevation (139m) than the control (134m). The dumpsite has much sand and clay mixture forming the topsoil which is soaked with leachate and highly conductive substances. The dumpsite has a thicker layer of topsoil compared to the control which is on a lower elevation and has other layers beginning almost at the surface of the ground.

Conclusion

The result of ERT conducted at the over 15 years dumpsite indicated the presence of leachate with resistivity values ≤ 8.71Ωm and up to 18.8 Ωm with active concentration at between 25m to 75m along the horizontal profile in 2-Dimension. The identified leachate has penetrated a depth of 11.35m. The leachate flows in the direction of decreasing elevation with the slope pattern towards the first electrode position at 0.00m along the horizontal profile. This implies that infiltration and percolation of leachate into the ground is yet to reach the aquifer since the drill depth of boreholes near the dumpsite is not less than 43.9m. Hence, borehole waters are not yet affected by the dumpsite leachate but will eventually be polluted as the leachate continues to infiltrate and percolate.

Acknowledgment

Many thanks to Akanimo F. Ibanga (fondly known as AK) – the technical expert who operated the Integrated Geo- Instrument Services (IGIS) device for being skillful and humane in what he does. Not left out in this appreciation is Eme Kalu who offered physical labour during the field practical.

References

[1]. Onwughara N. I., Ajiwe V. I. E. and Nnabuenyi H. O. (2013). Physicochemical Studies of Water from Selected Boreholes in Umuahia North Local Government Area, in Abia State, Nigeria: *International Journal of Pure & Applied Bioscience*; 1 (3): 34-44

[2]. International Solid Waste Association (ISWA) (2016). A Roadmap for closing Waste Dumpsites- The World's most Polluted Places: a report prepared as a part of ISWA's Scientific and Technical Committee Work-Program, *ISWA*, 19-20.

[3]. Archie G. E. (1942). The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics Transactions. American Institute of Mining, Metallurgical and Petroleum Engineers, Vol. 146, 54-62. Adapted from Igboekwe M. U. and Cyril N. N. (2011). Geostatistical Correlation of Aquifer Potentials in Abia State, South-Eastern Nigeria. *International Journal of Geosciences*, 2011. 541-548.

[4]. Brennan, R. B., Healy M.G., Morrison L., Hynes S., Norton D. and Clifford E. (2016). Management of landfill leachate. The legacy of European Union Directives. Waste Management. 355–363.

[5]. Akankpo A O. and Igboekwe M U. (2011). Monitoring Groundwater Contamination using Surface Electrical Resistivity and Geochemical Methods; *Journal of Water Resource and Protection*, 318-324

[6]. Maiti S.K., De S., Hazra T., Debsarkar A. and Dutta A. (2016). Characterization of Leachate and Its Impact on Surface and Groundwater Quality of a Closed Dumpsite - A Case Study at Dhapa, Kolkata, India. International Conference on Solid Waste Management. *Procedia Environmental Sciences* 35, 391 – 399

[7]. Rajkumar N., Subramani T. and Elango L. (2012). Impact of leachate on groundwater pollution due to non-engineered municipal solid waste landfill sites of erode city, Tamil Nadu, India. *Iranian Journal of Environmental Health Sciences & Engineering,* 9:35

[8]. Kurakalva R.M., Aradhi K.K., Mallela K.Y., and Venkatayogi S. (2016). Assessment of Groundwater Quality in and around the Jawaharnagar Municipal Solid Waste Dumping Site at Greater Hyderabad, Southern India. International Conference on Solid Waste Management. *Procedia Environmental Sciences* 35, 328 – 336

[9]. Naveen K. T., Rama R. P. and Naganjaneyulu K. (2015). Electrical resistivity imaging (ERI) using multielectrodes for studying subsurface formations in Cauvery plains. *Advances in Applied Science Research*, 6(5): 47-53

[10]. Lowrie W. (2007). Fundamentals of Geophysics – *Second Edition: Cambridge University Press*

[11]. Bernard J., Leite O. and Vermeersch F. (2004). Multi-electrode resistivity imaging for environmental and mining applications. *IRIS Instruments, Orleans, France,* 1-6

[12]. Balasubramanian A. (2007). Methods of Groundwater Exploration Technical Report: *Indian Social Science Congress-Trends in Earth Science Research*, 1-14

[13]. Ganiyu S. A., Badmus B. S., Oladunjoye M. A., Aizebeokhai A. P. and Olurin O. T. (2015). Delineation of Leachate Plume Migration Using Electrical Resistivity Imaging on Lapite Dumpsite in Ibadan, Southwestern Nigeria; *Geosciences*. 5(2): 70-80

[14]. Reynolds J. M. (1997). An introduction to applied and environmental geophysics. *John Wiley & Sons Publisher*. 796

[15]. Obasi P. N., Okoro A. U., Igwe E. O. and Edene E. N. (2015). Petrological Characterisitics and Paleodepositional Environment of the Sandstones of the Ameki Group (Eocene) In Bende and Isimkpu Areas, Southeastern Nigeria. *IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)* Volume 3, Issue 5 Ver. I, 09-15

[16]. Chikezie I. A, Eswaran H, Asawalam D. O and Ano A. O (2007). Characterization Of Two Benchmark Soils of Contrasting Parent Materials in Abia State, Southeastern Nigeria. *Global Journal of Pure and Applied Sciences* vol 16, no. 1, 23-29

[17]. Nnokwe N. N., Ibe K. K., Ibeneme S. I., Selemo A. O. and Nwagbara J. O. (2014). Geoelectrical Characterization of Rock Formations underlying Idonyi River, Amaeke-Abam, Southeastern Nigeria. *American Journal of Physics and Applications*. Vol. 2, No. 1, 35-45.

[18]. Resistivity meter (2019). Signal Stacking Resistivity Meter model SSR-MP-ATS. *Integrated Geo Instruments & Services Pvt. Ltd,* 1-2